# Analysis of Nitrogen Loading Reductions
# for Wastewater Treatment Facilities and Non-Point Sources
# in the Great Bay Estuary Watershed

## Appendix A:

## <u>Watershed Nitrogen Loads to the Great Bay Estuary</u>

NEW HAMPSHIRE DEPARTMENT OF
Environmental Services

DRAFT

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# 1 Introduction

In 2009, the New Hampshire Department of Environmental Services (DES) published a proposal for numeric nutrient criteria for the Great Bay Estuary (DES, 2009). These criteria were developed over a four-year period through an open process that involved local experts from universities, state agencies, federal agencies, municipalities, and non-governmental organizations. The report found that total nitrogen concentrations in most of the estuary needed to be less than 0.3 mg/L to prevent loss of eelgrass habitat and less than 0.45 mg/L to prevent occurrences of low dissolved oxygen. Eelgrass habitat and dissolved oxygen are both critical for supporting aquatic life in the Great Bay Estuary.

Based on these criteria and an analysis of a robust compilation of data from multiple sources, DES concluded that 11 of the 18 assessment zones in the Great Bay Estuary did not meet surface water quality standards and specifically did not comply with Env-Wq 1703.14, the narrative standard for nutrients (DES, 2009b). These impairments were added to New Hampshire's 2008 303(d) list on August 14, 2009, approved by EPA on September 30, 2009, and have subsequently been retained on the 2010 303(d) list. Nine of the 11 impaired assessment zones were the subestuaries of Great Bay, Little Bay, Upper Piscataqua River, and the tidal rivers that flow into these areas. The other two impaired assessment zones were Portsmouth Harbor and Little Harbor/Back Channel at the mouth of the estuary.

Under the Clean Water Act, if a water body is placed on the 303(d) list, a study must be completed to determine the existing loads of the pollutant and the load reductions that would be needed to meet the water quality standard. Nitrogen loads to the Great Bay Estuary have been estimated previously, but only for the whole estuary, not all of the smaller subestuaries that were added to the 303(d) list. Also, the contribution from individual point sources of nitrogen and the variability in nitrogen loads over time had not been adequately quantified.

For this analysis, nitrogen loads were determined for the subestuaries of Great Bay, Little Bay, Upper Piscataqua River, and the tidal rivers that flow into these areas. Nitrogen loads were determined for three two-year periods: 2003-2004, 2005-2006, and 2007-2008. These loads will be used to validate a model to predict nitrogen concentrations in the subestuaries from nitrogen loads. This model can than be used to predict how much nitrogen loads will have to be reduced for nitrogen concentrations in the estuary to meet the numeric criteria. Also, these loading estimates will be used to establish the relative contribution of individual point sources and non-point sources to the total nitrogen load for each subestuary. The impaired assessment zones of Portsmouth Harbor and Little Harbor/Back Channel were not included in this assessment because of insufficient data which necessitates a different modeling approach for these areas.

# 2 Methods

For the purposes of this evaluation, the following sources were identified that contribute to the nitrogen load to the Great Bay Estuary. It is assumed that these represent a complete accounting of contributing sources.

- Municipal Wastewater Treatment Facilities (WWTFs)
- Non-Point Sources (NPS) in Watersheds
- Groundwater Discharge to the Estuary
- Atmospheric Deposition to the Estuary

The nitrogen loads from these sources were estimated for three two-year periods: 2003-2004, 2005-2006, and 2007-2008. The methods for estimating the nitrogen loads are similar to those used by PREP (PREP, 2009) with minor differences.

The subestuaries included in this study were the Great Bay, Little Bay, Upper Piscataqua River, and the seven tidal rivers that flow into these areas. Nine of these ten subestuaries are impaired for nitrogen. The Winnicut River subestuary is the only one that is not impaired. This subestuary was included in the study because the Winnicut River watershed contributes nitrogen to the Great Bay, which is impaired.

The watersheds for each of the subestuaries are shown in Figures 1-11.

## *2.1 Nitrogen Loads from Municipal WWTFs*

### 2.1.1 WWTFs Upstream of Tidal Dams

This section applies to the eight WWTFs for Farmington, Rochester, Epping, Berwick, Milton, Rollinsford, Somersworth, and North Berwick.

The nitrogen load discharged from WWTFs to rivers was calculated as the product of the facility's average discharge and the average nitrogen concentration in the effluent.

Average discharge was calculated from monthly discharge monitoring reports. Specifically, for the 2003-2004 period, the monthly discharges between January 1, 2003 and December 31, 2004 were averaged to obtain an average discharge rate for the 2003-2004 period. The same method was used to estimate average discharge during the 2005-2006, and 2007-2008 periods.

The effluent nitrogen concentrations were determined from monthly measurements of effluent at eight WWTFs in 2008 (NHEP, 2008) or from data from 2008 provided by the operator of the facility. If no data were available for a facility, the average nitrogen concentration from the eight WWTFs monitored in 2008 (17.78 mg N/L) was used. The average nitrogen concentrations from 2008 were assumed to also be representative of other years between 2003 and 2007 because no other data were available. Only the Somersworth WWTF was upgraded to remove nutrients during this period so this assumption should be valid.

For WWTFs that discharge to rivers upstream of the estuary, some of the nitrogen discharged from the WWTF is lost during transit to the estuary. For these WWTFs, the nitrogen load should be reported in terms of its "delivered load" to the estuary. Following the methods of the USGS National SPARROW model (Smith et al., 1997), in-stream losses of nitrogen can be calculated by:

$$A = 1 - e^{-K*T}$$

where A is the fraction of the discharged nitrogen which is lost in transit through a river reach, K is the attenuation coefficient, and T is the travel time through the river reach. The USGS has completed a number of studies of nitrogen attenuation for their SPARROW models. The attenuation varies with the size of the stream with the greatest rates occurring in small streams and nearly zero attenuation in large rivers. In small streams with stream flows less than 100 or 200 cfs, the attenuation coefficient ranged between 0.76 and 0.77 $days^{-1}$ (Preston and Brakebill, 1999; Moore et al., 2004). Medium size streams with greater than 200 cfs but less than 1000 cfs had attenuation coefficients of 0.30 and 0.38 $days^{-1}$ (Preston and Brakebill, 1999; Smith et al., 1997). Finally, the attenuation coefficient for large rivers (>1000 cfs) were 0.07 to 0.12 $days^{-1}$ (Preston and Brakebill, 1999; Smith et al., 1997).

Given the available information from the USGS model, the nitrogen losses between a WWTF outfall and the Great Bay Estuary were calculated by a three step process. First, DES selected the river reaches in the New England SPARROW model between the outfall and the head of tide. For each reach, the model provided information on the reach length, the average water velocity, and the average flow. This information was used to calculate the travel time in the reach and to select the appropriate attenuation coefficient for the reach. (If the average flow was less than or equal to 200 cfs, the coefficient was 0.77 $days^{-1}$. For flows greater than 200 and less than or equal to 1000 cfs, the coefficient was 0.378 $days^{-1}$. Reaches with average flows greater than 1000 cfs used a coefficient of 0.103 $days^{-1}$. This approach and the coefficients were recommended by Daley et al., 2010.) Second, the equation from the SPARROW model was used to calculate the nitrogen losses within the reach. Third, the cumulative losses in all the reaches between the outfall and the estuary were calculated by combining the losses within each reach. Mathematically, this calculation was done by converting the percent of nitrogen lost within each reach to the percent of nitrogen remaining after each reach and then multiplying the percent remaining for all of the reaches. The cumulative losses of nitrogen for the WWTFs upstream of tidal dams are listed in Table 1.

### 2.1.2 WWTFs Downstream of Tidal Dams

This section applies to the six WWTFs for Durham, Exeter, Newfields, Newmarket, Dover, and South Berwick.

The nitrogen load discharged from WWTFs to tidal waters was calculated as the product of the facility's average discharge and the average nitrogen concentration in the effluent.

The same methods for determining average discharge and concentration for WWTFs upstream of tidal dams were used. However, because these discharges were directly to tidal waters, there was no attenuation of the nitrogen and the discharged load was equal to the delivered load.

### 2.1.3 WWTFs in Lower Piscataqua River

Even though the Lower Piscataqua River was not modeled for this report, the WWTFs that discharge to this subestuary contribute to the nitrogen loads to the Upper Piscataqua River, Little Bay, and Great Bay subestuaries. This section applies to the four WWTFs for Portsmouth, Kittery, Newington, and the Pease Tradeport (also operated by Portsmouth and sharing an outfall location with Newington).

The nitrogen load discharged from WWTFs to the Lower Piscataqua River was calculated as the product of the facility's average discharge and the average nitrogen concentration in the effluent. The same methods for determining average discharge and concentration for WWTFs upstream of tidal dams were used.

The Great Bay Particle Tracking Model was used to estimate the percent of the effluent from Portsmouth, Kittery, and Newington/Pease outfalls that reaches the Great Bay, Little Bay, and Upper Piscataqua River at steady state. This model was developed by Ata Bilgili of Dartmouth College to track the movement of conservative particles released anywhere in the estuary (Bilgili et al., 2005). In 2006, the output files for the model were provided to DES to use for simulations of estuarine circulation. The inputs for the model are the particle release location, the number of particles, the tide stage for the release, and how long the particles should be tracked. DES simulated the continuous release of effluent from the out falls by releasing particles from the outfall location every 3.1 hours. After 15 days of this continuous release, the particle distribution was assumed to have reached steady state. The number of particles that were in the Great Bay, Little Bay, and Upper Piscataqua River was divided by the total number of particles that had been released to estimate the percent of the effluent from the WWTFs that reaches these subestuaries.

The specific steps for this analysis are described below:

1. The movement of wastewater discharged from an outfall was simulated using the Great Bay Particle Tracking Model developed by Ata Bilgili of Dartmouth College (Bilgili et al., 2005). The model output files were transferred to DES in 2006.
2. DES simulated a release of 10 particles at the outfall at each of: high tide, mid-ebb, low tide, and mid-flood. The locations of the particles were tracked over 15 days. These simulations were run for both spring and neap tides. This means that the simulation began with a spring or neap tide amplitude, but was not "perpetually spring" or "perpetually neap". It was not possible to tailor the model inputs to match the neap-spring cycle of the tides. Future modeling work by Dartmouth College can resolve this inconsistency.

3. The output files from these eight simulations were delimited text files with fields for the particle number, time (since release), and coordinates (in NH State Plane-meters).
4. To simulate a continuous release, DES offset the release time for the simulations and superimposed the results. The four output files for spring tide amplitudes were combined into one continuous release simulation. The four output files for neap tides were combined into another continuous release simulation.
    a. The continuous release simulation was assumed to start at midnight with a high tide release. Therefore, the output file for the high tide release was used without a time offset.
    b. The next release of particles occurred at mid-ebb. For a 12.42 hour tide cycle, mid-ebb should occur approximately 186.3 minutes after high tide. Therefore, 186.3 minutes were added to the time in the output file for mid-ebb simulation. This file was combined with the high tide output file.
    c. The next release of particles occurred at low tide, which was assumed to be 186.3 minutes after mid-ebb. Therefore, 372.6 minutes were added to the time in the output file for low tide. This file was combined with the previous two files.
    d. The next release of particles occurred at mid-flood, which was assumed to be 186.3 minutes after low tide. Therefore, 558.9 minutes were added to the time in the output file for mid-flood. This file was combined with the previous three files.
    e. This process was continued with the next release of particles at high tide (the same file as used in step a) with an offset of 745.2 (12.42 hours).
    f. A total of 116 releases were added to the combined file to cover the 15 day period. Table 1 shows the offset times applied to each tide over a 15 day period.
    g. In order to reduce the number of rows in the combined file, the locations of the particles at midnight and noon were extracted and used in the GIS analysis.
5. The "steady-state" conditions were approximated by the location of all the particles at the end of 15 days ("Day 16 BEGIN (12 AM)"). The number of particles in each assessment zone was calculated using ArcGIS with a spatial join.
6. The percent of particles in each assessment zone was calculated by dividing the number in each zone by the total number of particles released through 15 days (1160).

The resulting percents for each assessment zone are shown in Table 2. For the Kittery, Newington/Pease, and Portsmouth outfalls, 20.3, 26.3, and 12.4%, respectively, of the discharged particles were in Great Bay, Little Bay, or the Upper Piscataqua River at steady state. Of these particles, the majority were concentrated in Little Bay (80%) with smaller amounts in the Great Bay (13%) and the Upper Piscataqua River (7%). Therefore, the delivered load from these WWTFs were calculated by multiplying the discharged load by the percent delivered to the upstream subestuaries and then further divided between Great Bay, Little Bay, and the Upper Piscataqua River. For example, the percent of effluent from the Portsmouth outfall in Little Bay would be 12.4% (the percent of Portsmouth effluent reaching Great Bay, Little Bay, or Upper Piscataqua River) multiplied by 80% (the percent of the delivered load that is specifically in Little Bay) or 9.9%.

## *2.2 Nitrogen Loads from Non-Point Sources in Watersheds*

### 2.2.1 NPS Upstream of Tidal Dams

DES used measurements of total nitrogen concentrations and stream flow in the eight tributaries to determine the total load of nitrogen delivered to the estuary by each tributary. The USGS LOADEST model was used to develop a calibrated model relating nitrogen concentrations and daily average stream flow (Runkel et al., 2004). The inputs to the LOADEST model were monthly measurements of total nitrogen concentrations and stream flow at the tidal dam for each river. Total nitrogen concentrations at the tidal dams were measured by DES between 2001 and 2007 and by UNH starting in 2008. Stream flow at the tidal dams was estimated from U.S. Geological Survey stream gages in the watersheds and drainage area transposition factors (Table 3).

The NPS delivered load was calculated by subtracting the delivered nitrogen load due to upstream WWTFs from the total measured load at each of the tidal dams. For some tributaries, there were no WWTFs upstream of the dam so the total measured load was attributed to NPS. For this assessment, DES has considered WWTFs to be the only point sources of nitrogen. However, stormwater from municipal separate storm sewer systems (MS4) with NPDES permits are also technically point sources. These stormwater sources were lumped with other NPS because DES was not able to quantify how much of the stormwater was derived from MS4 systems.

For the Great Works River, nitrogen loading data were only available for the 2007-2008 period. To estimate the NPS load in 2003-2004 and 2005-2006, DES used regressions between the NPS load and land use statistics from the watersheds that were monitored during these periods. Specifically, the NPS load from six of the watersheds was divided by the watershed drainage area to calculate the NPS yield with units of tons per year per square mile. The NPS loads from the Cocheco River were excluded from this regression because large point sources in the upstream watershed gave this value too much uncertainty. The NPS yields were regressed against the percent of the drainage area classified as developed or agriculture from 2006 imagery. Different regressions were developed for 2003-2004 and 2005-2006 under the assumption that the NPS yield would change based on precipitation (Figure 12). Both regressions were statistically significant at the $p<0.10$ level. The regressions were used to predict that the NPS load from the Great Works River watershed (15.3% developed and agriculture) was 71 and 107 tons/year in 2003-2004 and 2005-2006, respectively. These estimates corresponded well with the measured load from 2007-2008 of 61 tons/year.

### 2.2.2 NPS Downstream of Tidal Dams

The watershed boundaries for the subestuaries often did not end at the tidal dam. A portion of the watershed would exist below the dam from which runoff would be discharged to the subestuary. In Figures 1-11, these areas are shown in green. The NPS loads from these areas were estimated using the percent of land shown as developed or agriculture in the drainage area and the regressions developed between NPS yields and land use for the 2003-2004, 2005-2006, and 2007-2008 periods (Figure 12). The regressions were developed for a range of land use from 11.6 to 30.8% developed or agriculture. These shoreland areas typically were more developed than this range (25.5 to 57.1%). Therefore, the use of these regressions is an extrapolation of a linear model outside the calibration range.

## *2.3 Nitrogen Loads from Groundwater Discharge to the Estuary*

Some groundwater flow and nitrogen loading was accounted for in the NPS loading estimates. However, regional groundwater flow was also expected to contribute some nitrogen to the estuaries. Ballestero et al. (2004) measured the nitrogen loading rate from groundwater seeps to be 0.13 tons N/yr per mile of tidal shoreline. DES applied this loading rate to the length of tidal shoreline in each subestuary to estimate the groundwater loading rate. The groundwater loading rate was assumed to be constant for all years because no other information was available.

## *2.4 Nitrogen Loads from Atmospheric Deposition to the Estuary*

Atmospheric deposition of nitrogen directly to the estuary surface was estimated by multiplying the average deposition rate provided by Daley et al. (2010) (2.11 tons/mi2/yr or 7.41 kg/ha/yr) by the surface area of the estuary. This loading rate was assumed to be constant for all years because it only affects nitrogen loading directly to the estuary surface, which is a very small component of the total load. Atmospheric deposition of nitrogen to the land surface is accounted for in the NPS load contribution.

## *2.5 Total Nitrogen Loads*

For individual subestuaries, the total nitrogen load was calculated by summing the individual components of the nitrogen load: Delivered WWTF loads, NPS loads from above the tidal dam, NPS loads from below the tidal dam, groundwater loads, and atmospheric deposition to the estuary.

For the Great Bay, Little Bay, and Upper Piscataqua River, the total nitrogen load was the sum of the loads from contributing watersheds plus loads from shoreland areas surrounding the water body that are not part of the contributing watersheds. For example, the total load to Great Bay was the sum of the loads to the Winnicut, Exeter, and Lamprey subestuaries plus the NPS and groundwater loads from the shoreland areas immediately surrounding Great Bay. The contributing areas for Great Bay, Little Bay, and the Upper Piscataqua River are summarized in the following table.

| Subestuary | Contributing Watersheds |
|---|---|
| Great Bay | Winnicut River, Exeter River, Lamprey River, shoreland areas surrounding Great Bay |
| Little Bay | Great Bay, Oyster River, Bellamy River, shoreland areas surrounding Little Bay |
| Upper Piscataqua River | Cocheco River, Salmon Falls River, shoreland areas surrounding the Upper Piscataqua River |

# 3 Results

## *3.1 Nitrogen Loads from Municipal WWTFs*

The delivered nitrogen load from the 18 WWTFs to the study subestuaries was 353, 413, and 372 tons/year in 2003-2004, 2005-2006, and 2007-2008, respectively. The average delivered load for 2003-2008 was 379 tons/year.

Four of the 18 WWTFs contributed the majority of the delivered nitrogen load. The average delivered load between 2003 and 2008 for Rochester, Dover, Exeter, and Newmarket was 127, 104, 43, and 30 tons/year, respectively. These four plants contributed 304 tons/year on average, which is 80% of the total delivered nitrogen load from WWTFs to the study estuaries. Rochester and Dover alone provided 61% of the delivered load.

Eight WWTFs provided less than 5% of the delivered load on average: Epping, Rollinsford, Farmington, Pease ITP, North Berwick, Milton, Newfields, and Newington. The delivered load from each of these plants was less than 5 tons/year.

The remaining six WWTFs (Portsmouth, Durham, Somersworth, Berwick, Kittery, South Berwick) provided between 6 and 14 tons/year on average.

These numbers indicate that Rochester, Dover, Exeter, and Newmarket are the most important WWTFs for contribution of nitrogen to the Great Bay, Little Bay, and Upper Piscataqua River and the tidal rivers that flow into these areas. However, the WWTFs with small contributions should not be overlooked because these WWTFs may cause local impacts in the subestuary where they discharge. This fact is especially important for the dischargers to the Lower Piscataqua River. Only the fraction of the nitrogen discharged to the Lower Piscataqua River that reaches the Great Bay, Little Bay, and Upper Piscataqua River was considered for this study. The rest of the nitrogen discharged to the Lower Piscataqua River may result in local water quality problems. A specific study related to the Lower Piscataqua River, Portsmouth Harbor, and Little Harbor/Back Channel is needed to determine these local impacts.

The delivered nitrogen loads for individual WWTFs are shown on Table 4 and Figure 13.

## 3.2 Nitrogen Loads from Non-Point Sources in Watersheds

The NPS nitrogen load from the eight watersheds above the tidal dams was 692, 1002, and 797 tons/year in 2003-2004, 2005-2006, and 2007-2008, respectively. The average nitrogen load from these watersheds between 2003 and 2008 was 830 tons/year. The largest loads were from the Exeter, Lamprey, Cocheco and Salmon Falls Rivers. These four rivers accounted for 81% of the NPS load from watersheds above tidal dams.

The total NPS load from shoreland areas downstream of the tidal dams was 117, 204, and 144 tons/year in 2003-2004, 2005-2006, and 2007-2008, respectively. The average nitrogen load from these shoreland areas between 2003 and 2008 was 155 tons/year. The largest load was from the shorelands along the tidal portion of the Exeter River. The smallest contribution was from the shorelands in the tidal Lamprey River. These loads were estimated based on drainage area and land use. Since the shoreland area for the Exeter River is large and the shoreland area for the Lamprey River is small, these results were expected.

The delivered nitrogen loads from NPS in watersheds are shown on Tables 5 and 6 and Figures 14 and 15.

## 3.3 Nitrogen Loads from Groundwater Discharge to the Estuary

The study subestuaries have a total of 111.89 miles of tidal shoreline. Applying the groundwater discharge rate of 0.13 tons/mi/yr from Ballestero et al. (2004), the total nitrogen load from groundwater to the study subestuaries was 15 tons/year. The load from groundwater only accounts for nitrogen that discharges directly to the estuary. Nitrogen transported through groundwater to rivers and streams in the watershed was accounted for in the nitrogen loads from NPS in watersheds. The nitrogen load from groundwater discharge was assumed to be constant between 2003 and 2008.

## 3.4 Nitrogen Loads from Atmospheric Deposition to the Estuary

The study subestuaries have a total of 13.58 square miles of surface area for the tidal waters. Applying the atmospheric deposition rate of 2.11 tons/mi$^2$/year from Daley et al. (2010) results in 29 tons/year. Atmospheric nitrogen that was deposited to the land surface in the watershed was accounted for in the nitrogen loads from NPS in watersheds. The atmospheric loading rate was assumed to be constant between 2003 and 2008.

## 3.5 Total Nitrogen Loads

The total nitrogen loads to the study subestuaries were 1206, 1662, and 1355 tons/year in 2003-2004, 2005-2006, and 2007-2008, respectively. The average total load between 2003 and 2008 was 1408 tons/year. Nitrogen loads were highest in 2005-2006, which was the period with the highest rainfall. Point sources (WWTFs) accounted for 27% of the total load on average, with NPS (from watersheds, groundwater, and atmospheric deposition) making up the balance (73%).

The results for each of the study subestuaries are provided in Tables 7-10 and Figure 16.

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# 5 Tables

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**Table 1: Nitrogen attenuation for WWTFs discharging to rivers in the watershed of the Great Bay Estuary**

| WWTF | Percent of Discharged Nitrogen Lost in Transit to the Estuary | Percent Delivered |
|---|---|---|
| Farmington | 58.07% | 41.93% |
| Rochester | 24.44% | 75.56% |
| Epping | 41.80% | 58.20% |
| Berwick | 5.45% | 94.55% |
| Milton | 34.30% | 65.70% |
| Rollinsford | 1.04% | 98.96% |
| Somersworth | 5.06% | 94.94% |
| North Berwick | 48.44% | 51.56% |

**Table 2: Percent of Particles Discharged from the Kittery, Newington/Pease, and Portsmouth (Peirce Island) Outfalls that Were in Each Assessment Zone After a 15 Day Continuous Release**

| | **Kittery** | | **Newington/Pease** | | **Portsmouth** | |
|---|---|---|---|---|---|---|
| **Zone** | Neap | Spring | Neap | Spring | Neap | Spring |
| Great Bay | 0.6% | 6.4% | 1.0% | 4.5% | 0.8% | 1.7% |
| Little Bay | 16.7% | 14.7% | 22.4% | 20.7% | 11.9% | 8.0% |
| Oyster River | 0.1% | 0.4% | 2.6% | 0.4% | 0.6% | 0.3% |
| Bellamy River | 2.2% | 1.6% | 1.1% | 1.7% | 1.7% | 0.4% |
| Upper Piscataqua River | 1.0% | 1.2% | 2.2% | 1.8% | 2.2% | 0.2% |
| Salmon Falls River | 0.0% | 0.0% | 0.0% | 0.1% | 0.0% | 0.0% |
| Lower Piscataqua River-North | 10.9% | 10.6% | 17.3% | 17.9% | 9.0% | 4.7% |
| Lower Piscataqua River-South | 14.5% | 15.9% | 17.9% | 16.5% | 10.3% | 16.1% |
| Spinney Creek | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.2% |
| North Mill Pond | 0.0% | 0.2% | 0.0% | 0.0% | 0.0% | 0.1% |
| Portsmouth Harbor | 10.7% | 9.8% | 9.5% | 6.8% | 12.6% | 10.3% |
| Chauncey Creek | 0.1% | 0.3% | 0.0% | 0.2% | 1.5% | 0.3% |
| Spruce Creek | 0.3% | 0.3% | 0.3% | 0.0% | 0.3% | 0.4% |
| Little Harbor/Back Channel | 2.4% | 1.3% | 1.5% | 2.9% | 3.2% | 2.7% |
| Sagamore Creek | 0.0% | 0.1% | 0.0% | 0.1% | 0.1% | 0.1% |
| Berrys Brook | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.1% |
| Atlantic Ocean | 40.4% | 37.3% | 24.1% | 26.4% | 45.9% | 54.4% |
| | | | | | | |
| Average for Great Bay | 3.5% | | 2.8% | | 1.3% | |
| Average for Little Bay | 15.7% | | 21.6% | | 10.0% | |
| Average for Upper Piscataqua River | 1.1% | | 2.0% | | 1.2% | |
| **Total Delivered Load Percent** | **20.3%** | | **26.3%** | | **12.4%** | |

**Table 3: Stream flow transposition factors for tributaries to the Great Bay Estuary**

| Head-of-Tide Monitoring Station | Watershed Area for Station (sq miles) | USGS Streamgage Number | Watershed Area for Streamgage (sq miles) | Flow Multipier for Transpositions | Comments |
|---|---|---|---|---|---|
| Lamprey River (05-LMP) | 211.56 | 01073500 | 183 | 1.16 | |
| Exeter River (09-EXT) | 106.92 | 01073587 | 63.5 | 1.68 | |
| Oyster River (05-OYS) | 19.83 | 01073000 | 12.1 | 1.64 | |
| Cocheco River (07-CCH) | 175.23 | 01072800 | 85.7 | 2.04 | |
| Salmon Falls River (05-SFR) | 235.00 | 01073500 | | 1.28 | CFSM transposition with Lamprey gage |
| Bellamy River (05-BLM) | 27.30 | 01072800 | | 0.16 | 50% of flow from CFSM transposition with Cocheco gage |
| | | 01073000 | | 1.13 | 50% of flow from CFSM transposition with Oyster gage |
| Winnicut River (02-WNC) | 14.24 | 01073785 | 14.1 | 1.01 | For 2002, use CFSM transposition with Oyster gage |
| Great Works River (02-GWR) | 86.70 | 01072800 | | 1.01 | CFSM transposition with Cocheco gage |

**Table 4: Nitrogen loads and water discharge from WWTFs in the watershed of the Great Bay Estuary in 2003-2004, 2005-2006, and 2007-2008**

| WWTF | Discharge Location | Ave. TN Conc. (mg/L) | Data Source[1] | Ave. Flow 2003-2004 (MGD)[2] | Ave. Flow 2005-2006 (MGD) | Ave. Flow 2007-2008 (MGD) | Delivery Factor[3] (%) | Delivered TN Load in 2003-2004 (tons/yr) | Delivered TN Load in 2005-2006 (tons/yr) | Delivered TN Load in 2007-2008 (tons/yr) |
|---|---|---|---|---|---|---|---|---|---|---|
| Durham | Oyster River (tidal) | 7.63 | NHEP (2008) | 0.952 | 1.108 | 0.982 | 100.00% | 11.04 | 12.85 | 11.39 |
| Exeter | Exeter River (tidal) | 14.43 | NHEP (2008) | 1.792 | 2.250 | 1.796 | 100.00% | 39.30 | 49.36 | 39.40 |
| Newfields | Exeter River (tidal) | 17.78 | Estimated | 0.049 | 0.066 | 0.061 | 100.00% | 1.31 | 1.78 | 1.65 |
| Newmarket | Lamprey River (tidal) | 30.10 | NHEP (2008) | 0.670 | 0.697 | 0.627 | 100.00% | 30.66 | 31.90 | 28.70 |
| Dover | Upper Piscataqua River (tidal) | 22.33 | NHEP (2008) | 2.837 | 3.343 | 2.984 | 100.00% | 96.30 | 113.49 | 101.29 |
| South Berwick | Salmon Falls River (tidal) | 9.95 | Municipality | 0.327 | 0.405 | 0.365 | 100.00% | 4.95 | 6.13 | 5.52 |
| Kittery | Lower Piscataqua River | 15.99 | NHEP (2008) | 1.023 | 1.271 | 1.168 | 20.30% | 5.05 | 6.27 | 5.76 |
| Newington | Lower Piscataqua River | 17.78 | Estimated | 0.128 | 0.154 | 0.151 | 26.34% | 0.91 | 1.10 | 1.08 |
| Portsmouth | Lower Piscataqua River | 13.34 | Municipality | 4.886 | 5.902 | 5.359 | 12.37% | 12.26 | 14.81 | 13.45 |
| Pease ITP | Lower Piscataqua River | 8.74 | Municipality | 0.529 | 0.795 | 0.693 | 26.34% | 1.85 | 2.78 | 2.43 |
| Farmington | Cocheco River | 12.97 | Municipality | 0.218 | 0.382 | 0.365 | 41.93% | 1.80 | 3.16 | 3.02 |
| Rochester | Cocheco River | 30.11 | NHEP (2008) | 3.462 | 3.918 | 3.680 | 75.56% | 119.70 | 135.46 | 127.25 |
| Epping | Lamprey River | 17.78 | Estimated | 0.235 | 0.314 | 0.274 | 58.20% | 3.69 | 4.94 | 4.31 |
| Berwick | Salmon Falls River | 16.68 | NHEP (2008) | 0.387 | 0.425 | 0.379 | 94.55% | 9.29 | 10.20 | 9.08 |
| Milton | Salmon Falls River | 17.78 | Estimated | 0.069 | 0.116 | 0.085 | 65.70% | 1.22 | 2.05 | 1.50 |
| Rollinsford | Salmon Falls River | 17.78 | Estimated | 0.099 | 0.115 | 0.105 | 98.96% | 2.64 | 3.07 | 2.80 |
| Somersworth | Salmon Falls River | 4.95 | NHEP (2008) | 1.201 | 1.628 | 1.602 | 94.94% | 8.58 | 11.64 | 11.46 |
| North Berwick | Great Works River | 17.78 | Estimated | 0.143 | 0.149 | 0.126 | 51.56% | 2.00 | 2.08 | 1.75 |
| Total | | | | 19.006 | 23.038 | 20.802 | | 352.55 | 413.07 | 371.82 |

1. For "NHEP (2008)", the concentration is the average of 10 grab samples collected during 2008. For "Municipality", the concentration is the average of samples collected by the municipality during 2008. For "Estimated", no data were available for this WWTF. The average TN concentration from NHEP (2008) was assumed.
2. The flows in this table are annual averages. The monthly average flows from NPDES discharge monitoring reports were averaged.
3. Delivery factor is the percent of the discharged load that is delivered to the GB/UPR estuary. For WWTFs in the watersheds, attenuation loss estimated using the travel time for water between the WWTF outfall and the estuary and a first order loss coefficient. For the WWTFs discharging to the Lower Piscataqua River, the delivery factor was estimated from the percent of particles in GB, LB, and UPR at steady state in the Dartmouth particle tracking model.

**Table 5: Non-point source nitrogen loads from upland watersheds in 2003-2004, 2005-2006, and 2007-2008**

| Tributary Watershed | Land Use (Percent in Developed & Agriculture) | Tributary Nitrogen Loads (tons/yr) | | | Upstream WWTF Delivered Load (tons/yr) | | | NPS Tributary Load (tons/yr) | | | NPS Nitrogen Yield (tons/yr/sq.mi.) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | '03-'04 | '05-'06 | '07-'08 | '03-'04 | '05-'06 | '07-'08 | '03-'04 | '05-'06 | '07-'08 | '03-'04 | '05-'06 | '07-'08 |
| Winnicut River at 02-WNC | 30.8% | 17.48 | 27.37 | 18.39 | 0.00 | 0.00 | 0.00 | 17.48 | 27.37 | 18.39 | 1.23 | 1.93 | 1.30 |
| Exeter River at 09-EXT | 22.2% | 80.64 | 158.89 | 162.61 | 0.00 | 0.00 | 0.00 | 80.64 | 158.89 | 162.61 | 0.75 | 1.49 | 1.52 |
| Lamprey River at 05-LMP | 11.6% | 170.46 | 258.42 | 184.14 | 3.69 | 4.94 | 4.31 | 166.76 | 253.48 | 179.83 | 0.79 | 1.20 | 0.85 |
| Oyster River at 05-OYS | 22.2% | 22.41 | 36.01 | 22.39 | 0.00 | 0.00 | 0.00 | 22.41 | 36.01 | 22.39 | 1.13 | 1.81 | 1.13 |
| Bellamy River at 05-BLM | 19.4% | 24.20 | 38.18 | 31.10 | 0.00 | 0.00 | 0.00 | 24.20 | 38.18 | 31.10 | 0.89 | 1.40 | 1.14 |
| Cocheco River at 07-CCH | 16.9% | 246.56 | 304.59 | 218.64 | 121.50 | 138.62 | 130.27 | 125.06 | 165.97 | 88.36 | 0.71 [1] | 0.95 [1] | 0.50 [1] |
| Salmon Falls River at 05-SFR | 13.1% | 206.04 | 242.36 | 257.69 | 21.73 | 26.96 | 24.84 | 184.31 | 215.40 | 232.85 | 0.78 | 0.92 | 0.99 |
| Great Works River at 02-GWR | 15.3% | NA | NA | 62.84 | 2.00 | 2.08 | 1.75 | 71.51 [2] | 106.9 [2] | 61.10 | NA | NA | 0.70 |

1. Value not used in regressions because of the high proportion of upstream WWTF load.
2. Value derived from land use and regressions, not measured.
3. Regression equations between land use and NPS nitrogen yield. For 2003-2004, Yield = 2.27*Land Use + 0.48 ($r^2$=0.61, n=6, p=0.065). For 2005-2006, Yield = 4.87*Land Use + 0.49 ($r^2$=0.81, n=6, p=0.014). For 2007-2008, Yield = 2.95*Land Use + 0.52 ($r^2$=0.51, n=7, p=0.07). Units for land use are percent of land in developed or agricultural classes. Units for NPS yield are tons/yr/$mi^2$.

**Table 6: Non-point source nitrogen loads from shoreland areas to adjacent to study subestuaries in 2003-2004, 2005-2006, and 2007-2008**

| Watershed | Units | Winnicut River | Exeter River | Lamprey River | Oyster River | Bellamy River | Cocheco River | Salmon Falls River | Great Bay | Little Bay | Upper Piscataqua |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Land Drainage Area Below Dam | (sq.mi.) | 4.45 | 19.29 | 1.70 | 10.67 | 5.83 | 9.49 | 7.30 | 15.56 | 3.48 | 11.54 |
| Developed | (sq.mi.) | 1.38 | 2.97 | 0.48 | 2.69 | 1.80 | 3.30 | 0.71 | 2.89 | 0.32 | 1.16 |
| Agriculture | (sq.mi.) | 0.61 | 3.14 | 0.22 | 1.45 | 1.41 | 2.13 | 1.40 | 2.07 | 0.99 | 1.78 |
| Developed & Agriculture | (%) | 44.71% | 31.71% | 41.08% | 38.74% | 55.16% | 57.14% | 28.87% | 31.89% | 37.50% | 25.49% |
| | | | | | | | | | | | |
| NPS Load from Area Below Dam[1,2] | | | | | | | | | | | |
| 2003-2004 | (tons/yr) | 6.64 | 23.11 | 2.40 | 14.48 | 10.08 | 16.85 | 8.28 | 18.71 | 4.62 | 12.19 |
| 2005-2006 | (tons/yr) | 11.86 | 39.22 | 4.23 | 25.34 | 18.49 | 31.05 | 13.84 | 31.78 | 8.05 | 19.97 |
| 2007-2008 | (tons/yr) | 8.19 | 28.14 | 2.95 | 17.78 | 12.53 | 20.97 | 10.04 | 22.78 | 5.67 | 14.71 |

1. Calculated from regression equations, not measured.
2. Note: The input variable for the regression was percent developed and agriculture relative to total area (including water) because the regression was derived using upland watersheds with relatively little water area. For tidal watersheds with large proportions of water area, the percentage was calculated using just the land area of the watershed.

**Table 7: Delivered nitrogen loads to study subestuaries in 2003-2004 (tons N/yr)**

| Source | Winnicut | Exeter | Lamprey | Oyster | Bellamy | Cocheco | Salmon Falls | Great Bay | Little Bay | Upper Piscataqua |
|---|---|---|---|---|---|---|---|---|---|---|
| WWTFs Upstream of Dam | 0.00 | 0.00 | 3.69 | 0.00 | 0.00 | 121.50 | 23.73 | 3.69 | 3.69 | 145.23 |
| WWTFs Downstream of Dam | 0.00 | 40.62 | 30.66 | 11.04 | 0.00 | 0.00 | 4.95 | 71.28 | 82.32 | 101.24 |
| WWTFs in Lower Piscataqua River | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 2.61 | 18.67 | 1.40 |
| NPS Upstream of Dam | 17.48 | 80.64 | 166.76 | 22.41 | 24.20 | 125.06 | 255.82 | 264.89 | 311.50 | 380.88 |
| NPS Downstream of Dam | 6.64 | 23.11 | 2.40 | 14.48 | 10.08 | 16.85 | 8.28 | 50.85 | 80.04 | 37.32 |
| Groundwater | 0.55 | 2.04 | 0.56 | 1.41 | 1.62 | 1.15 | 1.27 | 5.97 | 10.79 | 3.75 |
| Atmospheric Deposition to Tidal Waters | 0.41 | 1.01 | 0.36 | 1.06 | 1.44 | 0.59 | 1.20 | 15.67 | 24.19 | 4.47 |
| Subtotal - Point sources | 0.00 | 40.62 | 34.35 | 11.04 | 0.00 | 121.50 | 28.67 | 77.58 | 104.68 | 247.88 |
| Subtotal - Non-point sources | 25.08 | 106.80 | 170.08 | 39.37 | 37.34 | 143.64 | 266.57 | 337.38 | 426.52 | 426.42 |
| Total | 25.08 | 147.41 | 204.43 | 50.41 | 37.34 | 265.14 | 295.25 | 414.96 | 531.20 | 674.30 |
| | | | | | | | | | | |
| % Point Source | 0% | 28% | 17% | 22% | 0% | 46% | 10% | 19% | 20% | 37% |
| % NPS | 100% | 72% | 83% | 78% | 100% | 54% | 90% | 81% | 80% | 63% |

**Table 8: Delivered nitrogen loads to study subestuaries in 2005-2006 (tons N/yr)**

| Source | Winnicut | Exeter | Lamprey | Oyster | Bellamy | Cocheco | Salmon Falls | Great Bay | Little Bay | Upper Piscataqua |
|---|---|---|---|---|---|---|---|---|---|---|
| WWTFs Upstream of Dam | 0.00 | 0.00 | 4.94 | 0.00 | 0.00 | 138.62 | 29.04 | 4.94 | 4.94 | 167.66 |
| WWTFs Downstream of Dam | 0.00 | 51.14 | 31.90 | 12.85 | 0.00 | 0.00 | 6.13 | 83.04 | 95.90 | 119.62 |
| WWTFs in Lower Piscataqua River | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 3.24 | 23.21 | 1.75 |
| NPS Upstream of Dam | 27.37 | 158.89 | 253.48 | 36.01 | 38.18 | 165.97 | 322.34 | 439.75 | 513.94 | 488.31 |
| NPS Downstream of Dam | 11.86 | 39.22 | 4.23 | 25.34 | 18.49 | 31.05 | 13.84 | 87.09 | 138.97 | 64.85 |
| Groundwater | 0.55 | 2.04 | 0.56 | 1.41 | 1.62 | 1.15 | 1.27 | 5.97 | 10.79 | 3.75 |
| Atmospheric Deposition to Tidal Waters | 0.41 | 1.01 | 0.36 | 1.06 | 1.44 | 0.59 | 1.20 | 15.67 | 24.19 | 4.47 |
| Subtotal - Point sources | 0.00 | 51.14 | 36.84 | 12.85 | 0.00 | 138.62 | 35.17 | 91.23 | 124.04 | 289.02 |
| Subtotal - Non-point sources | 40.19 | 201.16 | 258.63 | 63.83 | 59.73 | 198.75 | 338.65 | 548.47 | 687.90 | 561.39 |
| Total | 40.19 | 252.30 | 295.47 | 76.68 | 59.73 | 337.37 | 373.82 | 639.70 | 811.94 | 850.41 |
| | | | | | | | | | | |
| % Point Source | 0% | 20% | 12% | 17% | 0% | 41% | 9% | 14% | 15% | 34% |
| % NPS | 100% | 80% | 88% | 83% | 100% | 59% | 91% | 86% | 85% | 66% |

**Table 9: Delivered nitrogen loads to study subestuaries in 2007-2008 (tons N/yr)**

| Source | Winnicut | Exeter | Lamprey | Oyster | Bellamy | Cocheco | Salmon Falls | Great Bay | Little Bay | Upper Piscataqua |
|---|---|---|---|---|---|---|---|---|---|---|
| WWTFs Upstream of Dam | 0.00 | 0.00 | 4.31 | 0.00 | 0.00 | 130.27 | 26.59 | 4.31 | 4.31 | 156.86 |
| WWTFs Downstream of Dam | 0.00 | 41.04 | 28.70 | 11.39 | 0.00 | 0.00 | 5.52 | 69.74 | 81.13 | 106.81 |
| WWTFs in Lower Piscataqua River | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 2.95 | 21.12 | 1.59 |
| NPS Upstream of Dam | 18.39 | 162.61 | 179.83 | 22.39 | 31.10 | 88.36 | 293.94 | 360.83 | 414.32 | 382.30 |
| NPS Downstream of Dam | 8.19 | 28.14 | 2.95 | 17.78 | 12.53 | 20.97 | 10.04 | 62.07 | 98.04 | 45.73 |
| Groundwater | 0.55 | 2.04 | 0.56 | 1.41 | 1.62 | 1.15 | 1.27 | 5.97 | 10.79 | 3.75 |
| Atmospheric Deposition to Tidal Waters | 0.41 | 1.01 | 0.36 | 1.06 | 1.44 | 0.59 | 1.20 | 15.67 | 24.19 | 4.47 |
| Subtotal - Point sources | 0.00 | 41.04 | 33.01 | 11.39 | 0.00 | 130.27 | 32.11 | 77.00 | 106.56 | 265.26 |
| Subtotal - Non-point sources | 27.54 | 193.80 | 183.70 | 42.63 | 46.70 | 111.07 | 306.45 | 444.53 | 547.35 | 436.25 |
| Total | 27.54 | 234.84 | 216.71 | 54.02 | 46.70 | 241.34 | 338.57 | 521.54 | 653.90 | 701.51 |
| | | | | | | | | | | |
| % Point Source | 0% | 17% | 15% | 21% | 0% | 54% | 9% | 15% | 16% | 38% |
| % NPS | 100% | 83% | 85% | 79% | 100% | 46% | 91% | 85% | 84% | 62% |

**Table 10: Average delivered nitrogen loads to study subestuaries in 2003-2008 (tons N/yr)**

| Source | Winnicut | Exeter | Lamprey | Oyster | Bellamy | Cocheco | Salmon Falls | Great Bay | Little Bay | Upper Piscataqua | Total[1] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Point Sources | 0.00 | 44.27 | 34.73 | 11.76 | 0.00 | 130.13 | 31.98 | 81.94 | 111.76 | 267.39 | 379.15 |
| Non-Point Sources | 30.94 | 167.25 | 204.14 | 48.61 | 47.92 | 151.15 | 303.89 | 443.46 | 553.92 | 474.69 | 1,028.61 |
| **Total** | **30.94** | **211.52** | **238.87** | **60.37** | **47.92** | **281.29** | **335.88** | **525.40** | **665.68** | **742.07** | **1,407.76** |
| Percent Point Sources | 0% | 21% | 15% | 19% | 0% | 46% | 10% | 16% | 17% | 36% | 27% |
| Percent Non-Point Sources | 100% | 79% | 85% | 81% | 100% | 54% | 90% | 84% | 83% | 64% | 73% |

Notes:
1. Total loads are the sum of the loads to Little Bay and Upper Piscataqua. This value represents the total watershed nitrogen loading to all subestuaries above Dover Point.

# 6 Figures

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**Figure 1: Watersheds draining to the Great Bay Estuary**

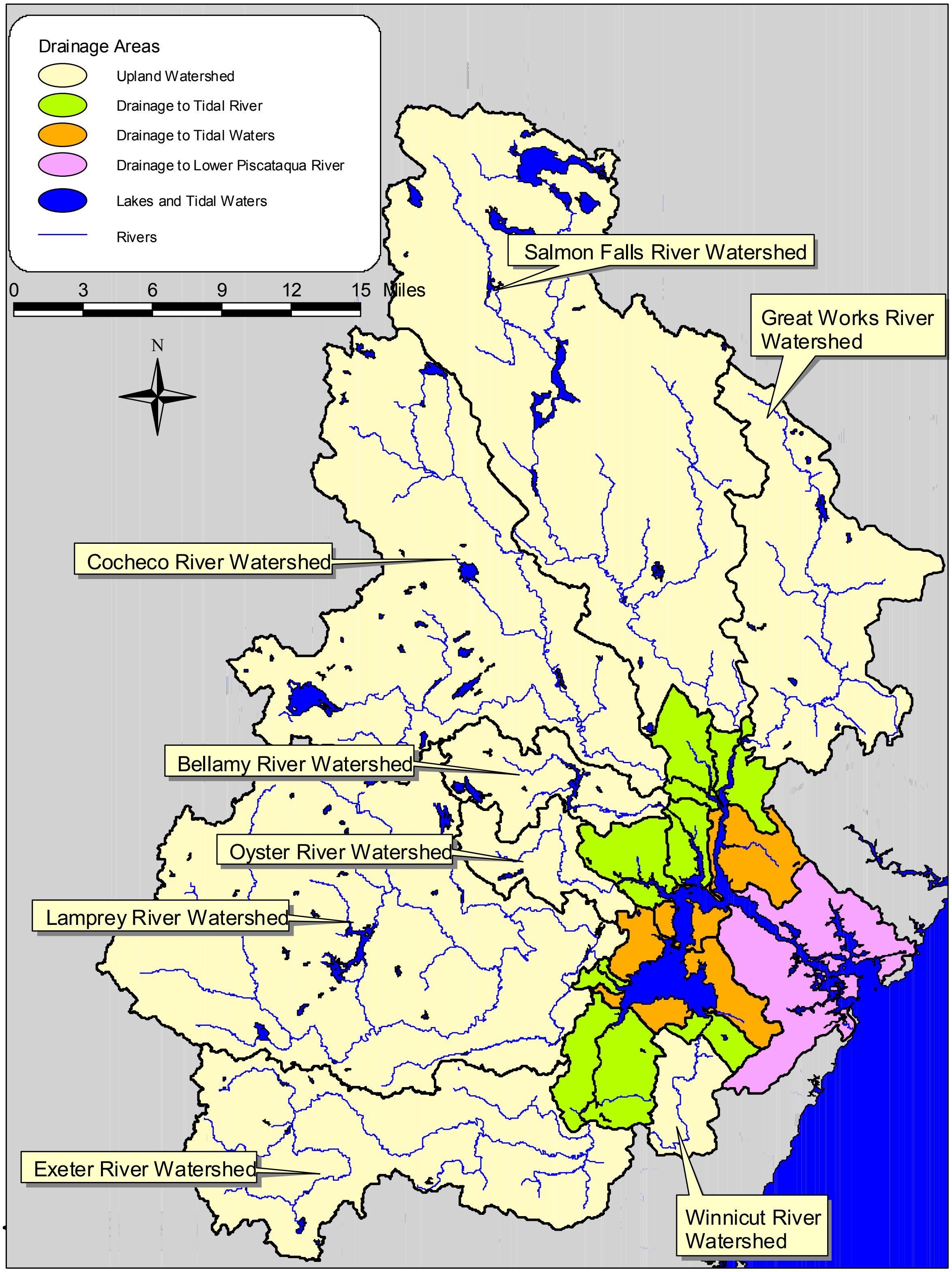

**Figure 2: Watershed for the Winnicut River subestuary**

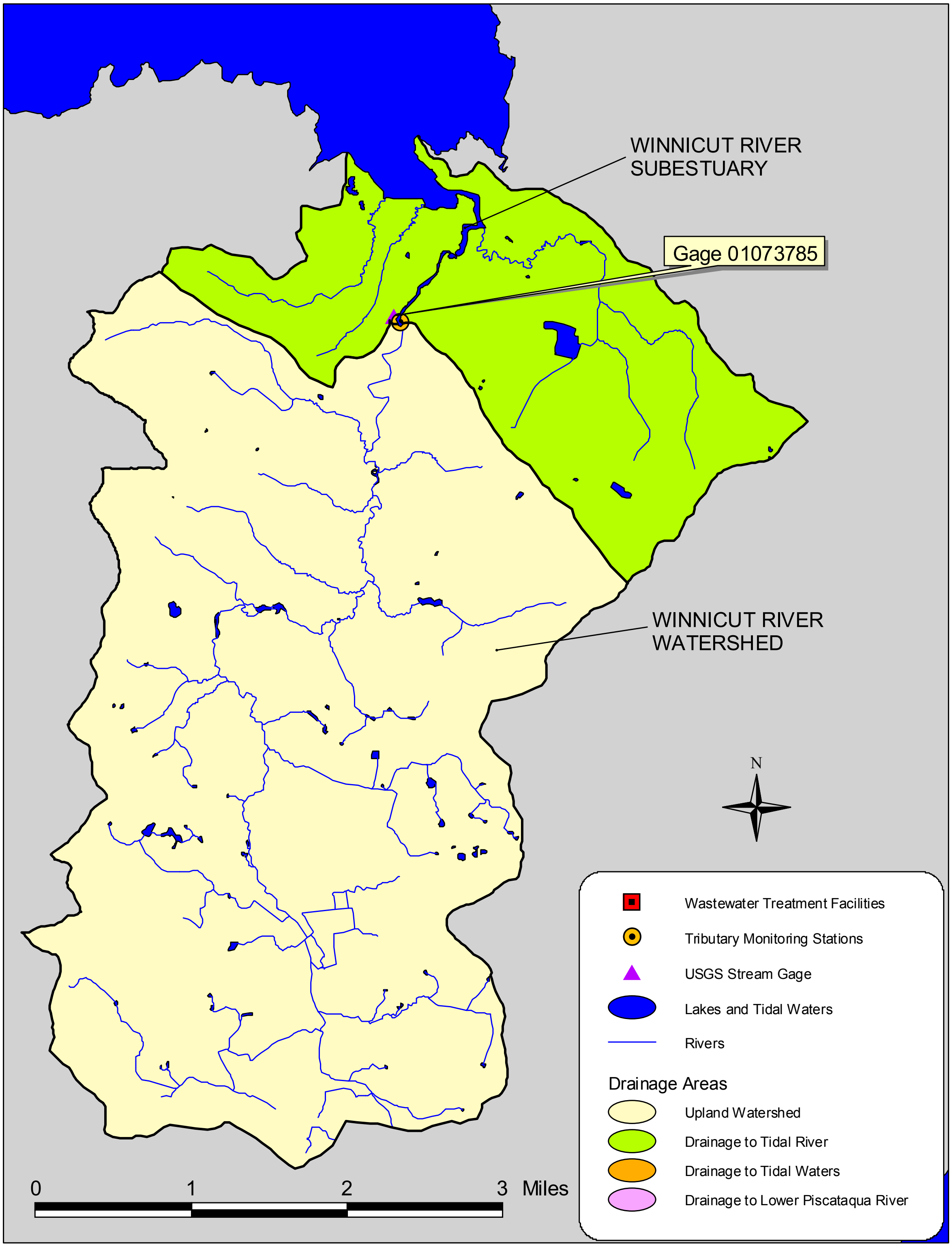

**Figure 3: Watershed for the Exeter/Squamscott River subestuary**

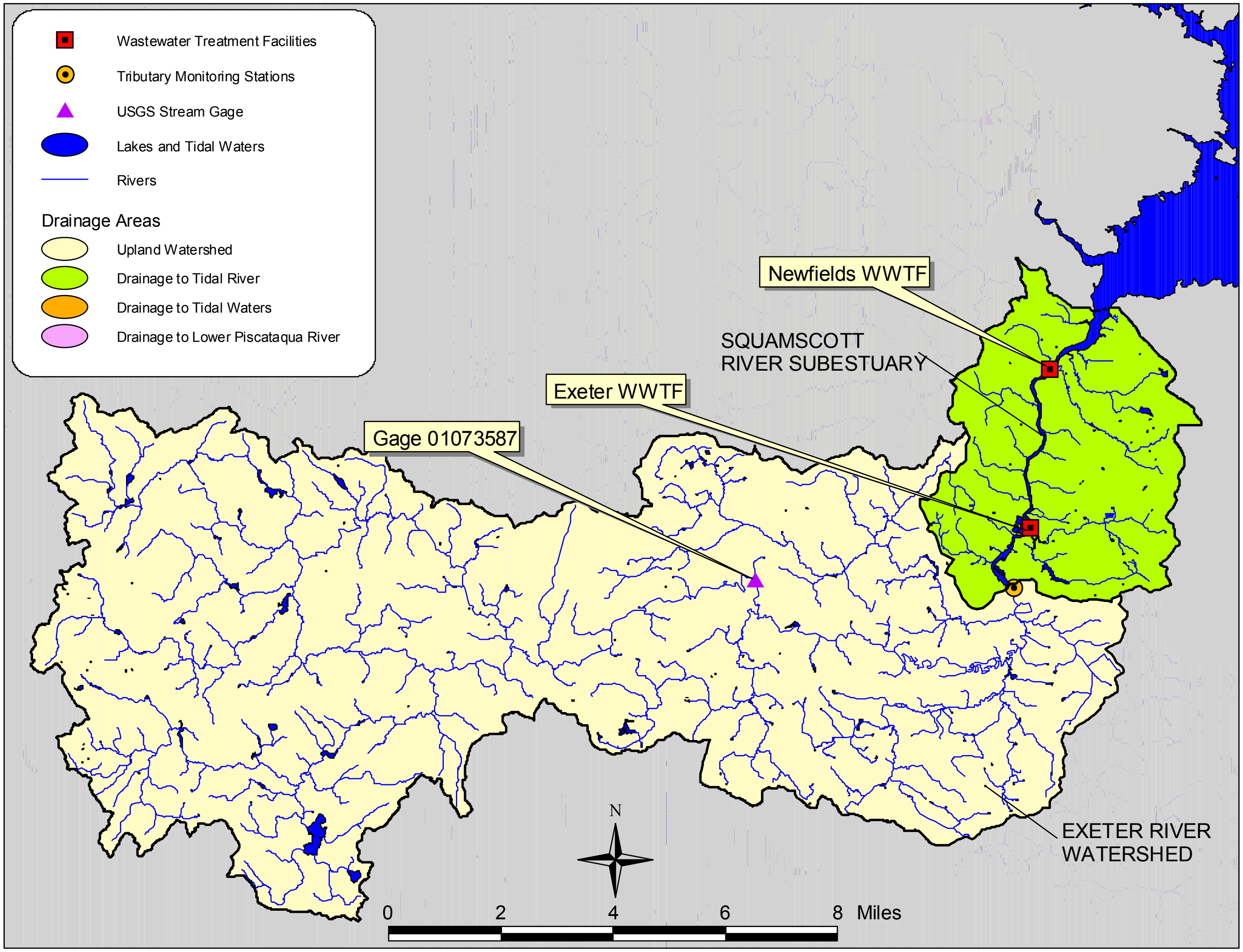

**Figure 4: Watershed for the Lamprey River subestuary**

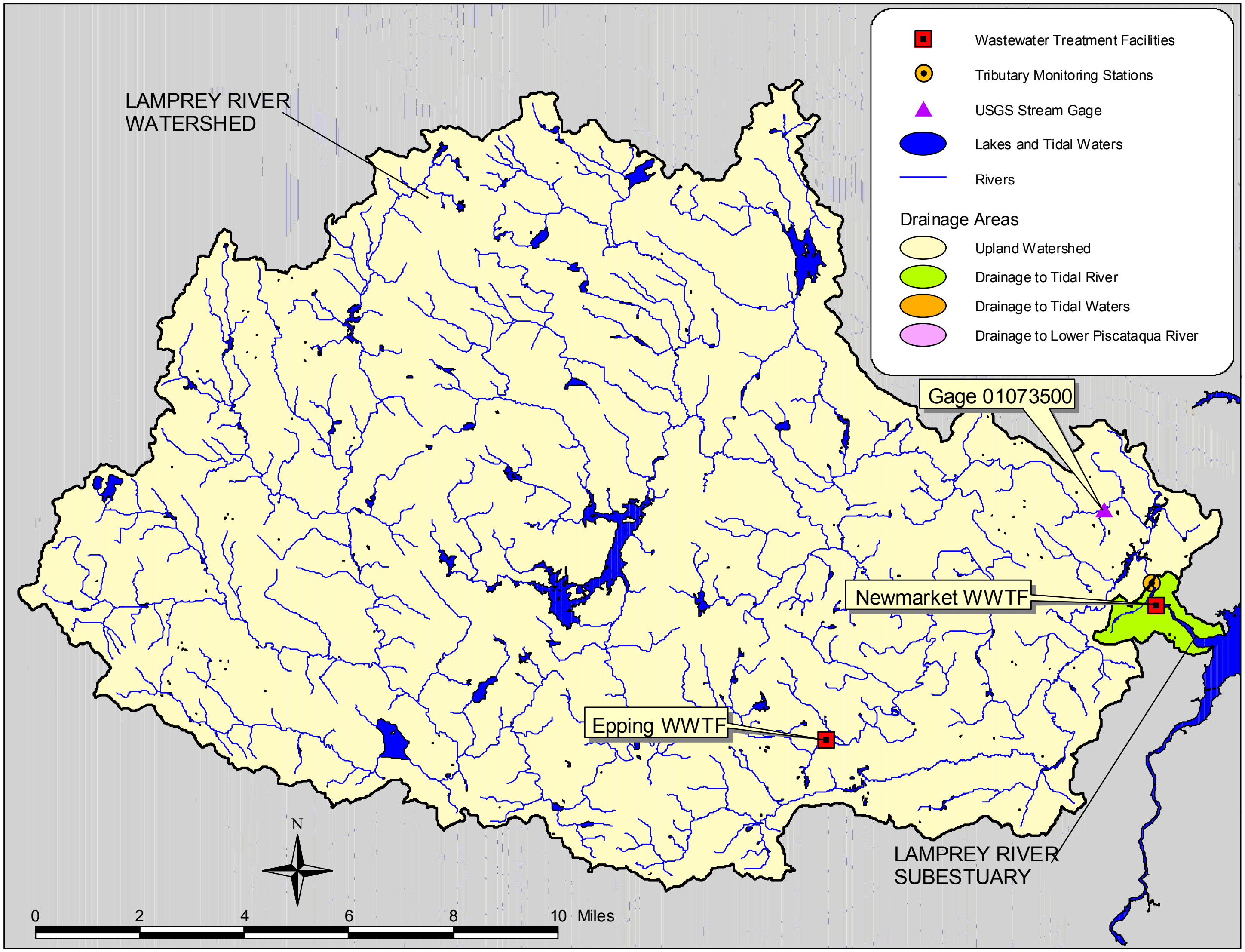

**Figure 5: Watershed for the Oyster River subestuary**

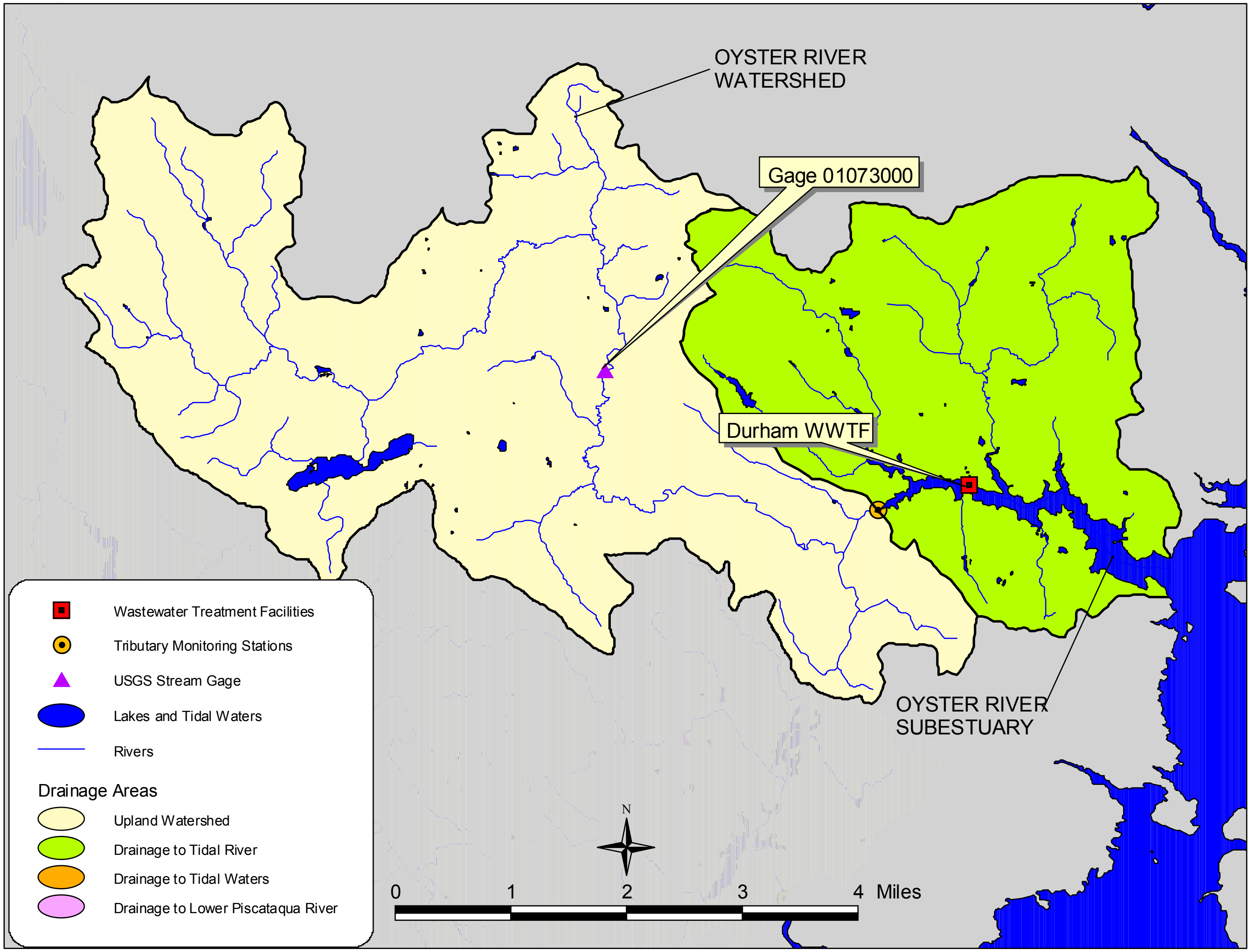

**Figure 6: Watershed for the Bellamy River subestuary**

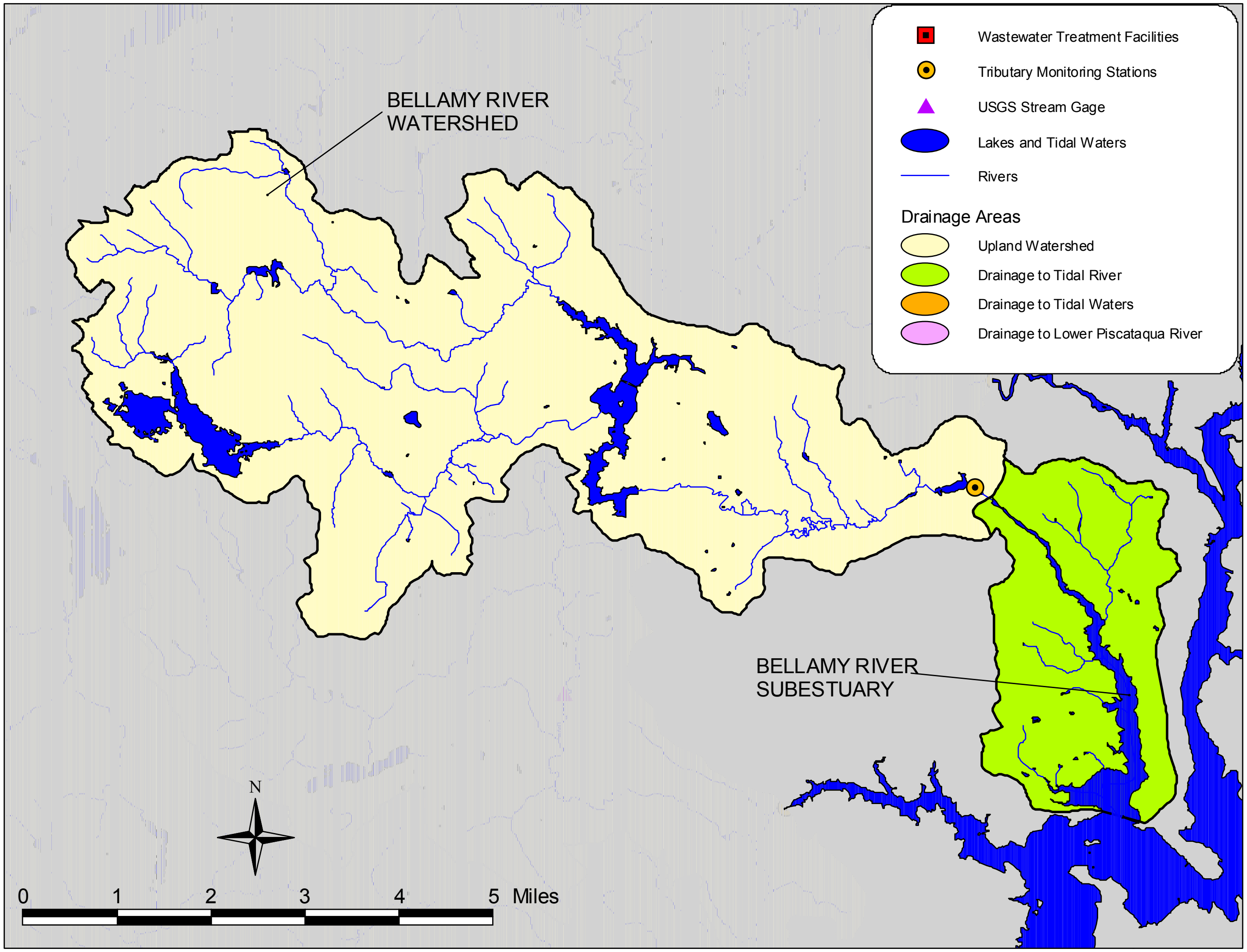

**Figure 7: Watershed for the Cocheco River subestuary**

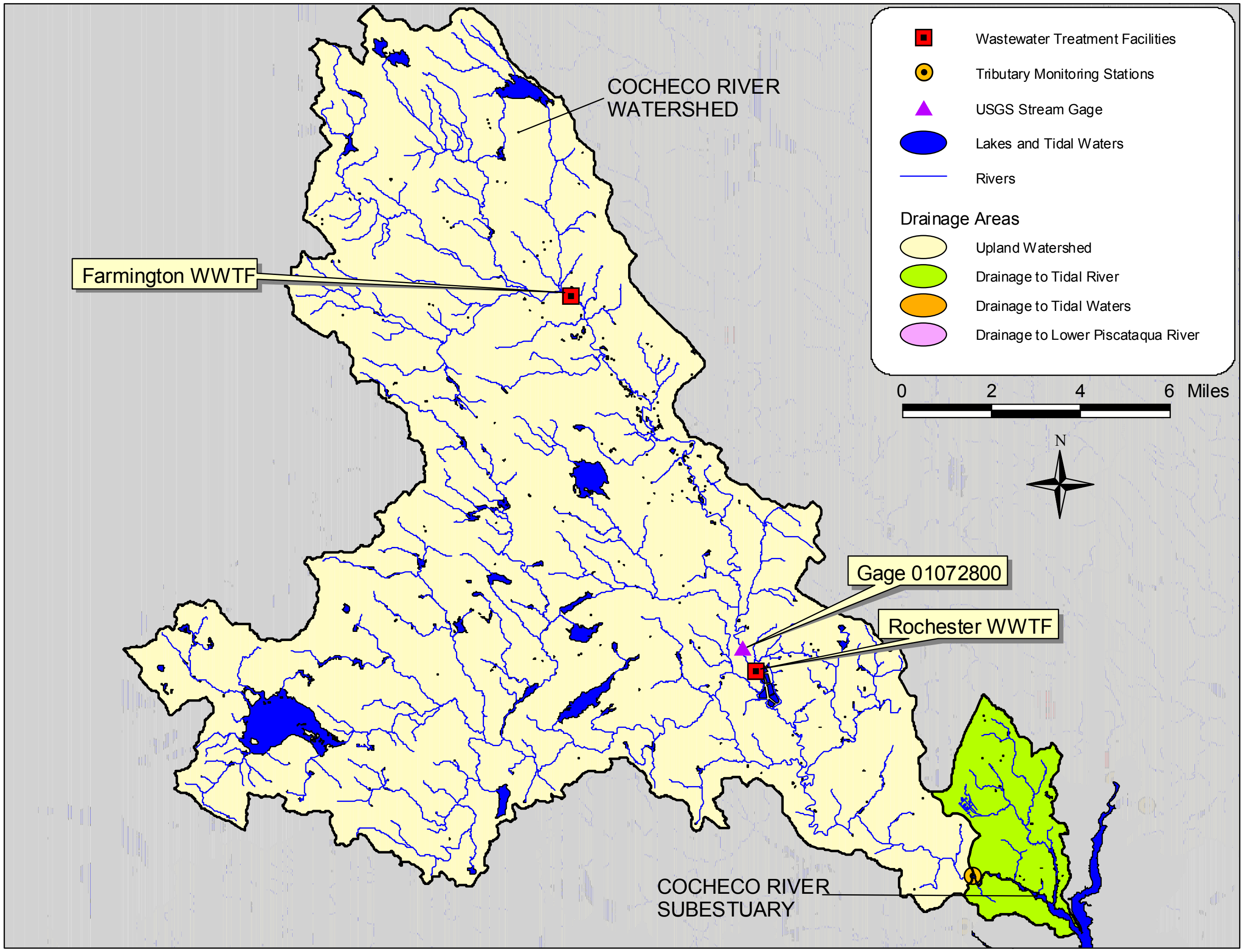

**Figure 8: Watershed for the Salmon Falls River subestuary**

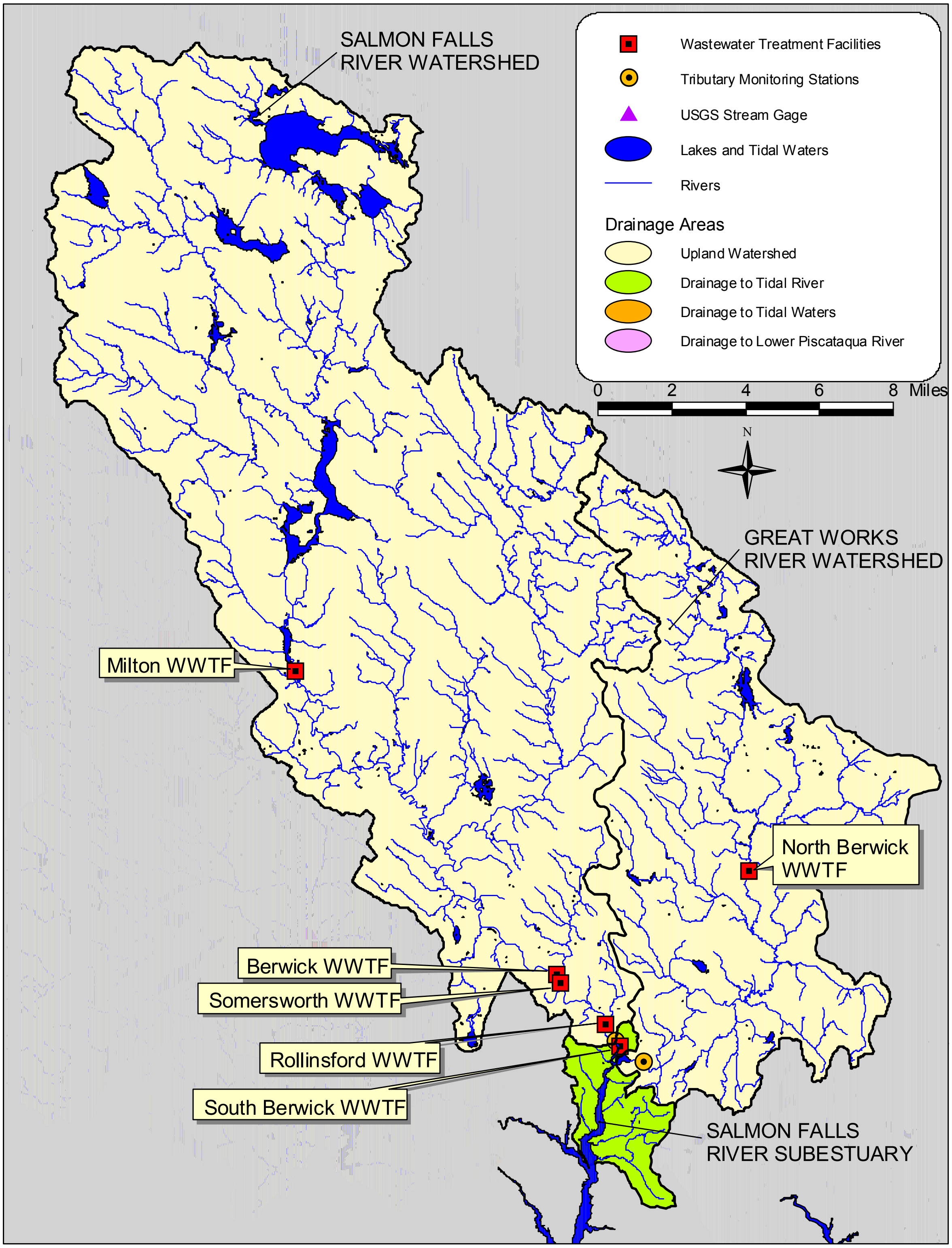

**Figure 9: Watershed for the Great Bay subestuary**

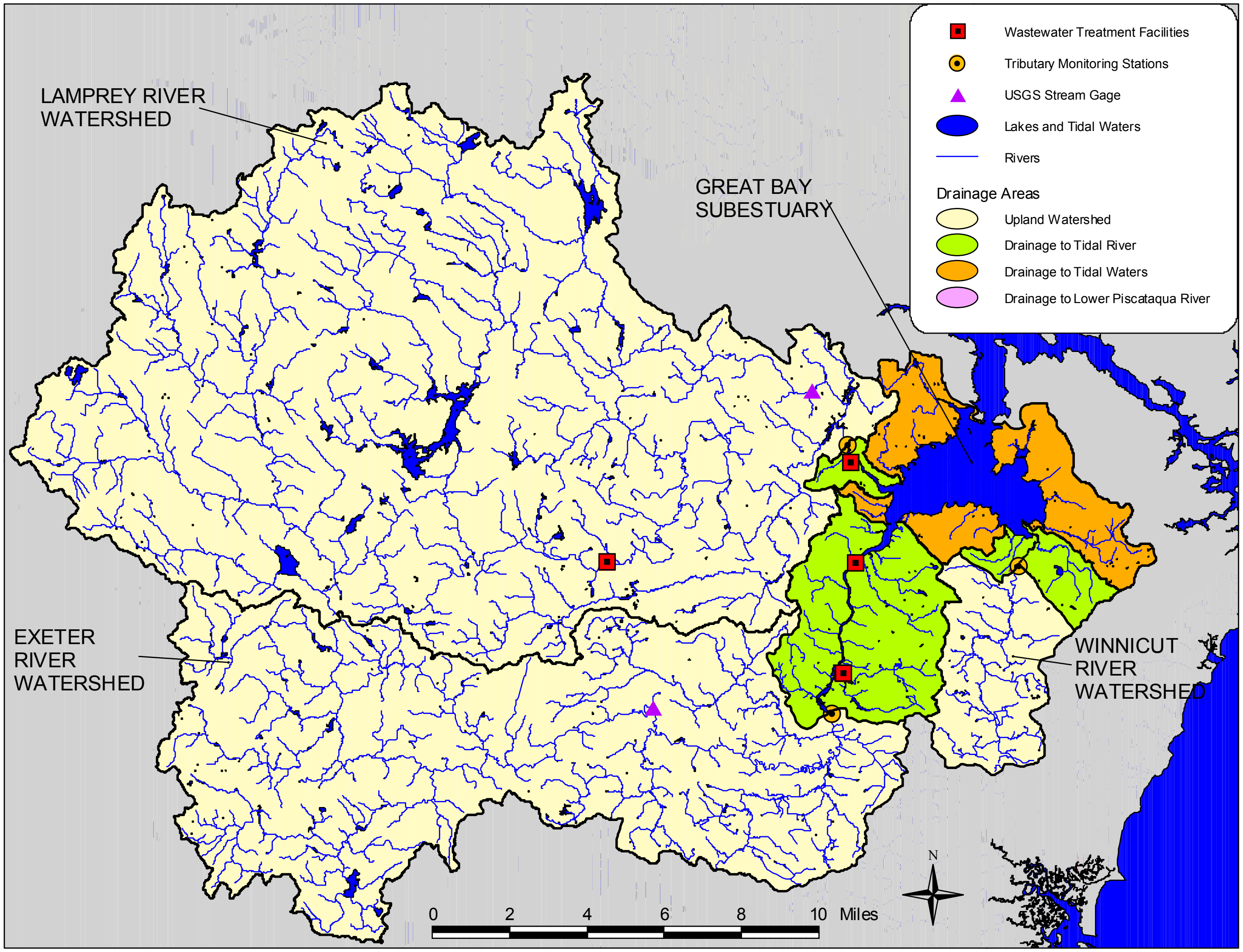

**Figure 10: Watershed for the Little Bay subestuary**

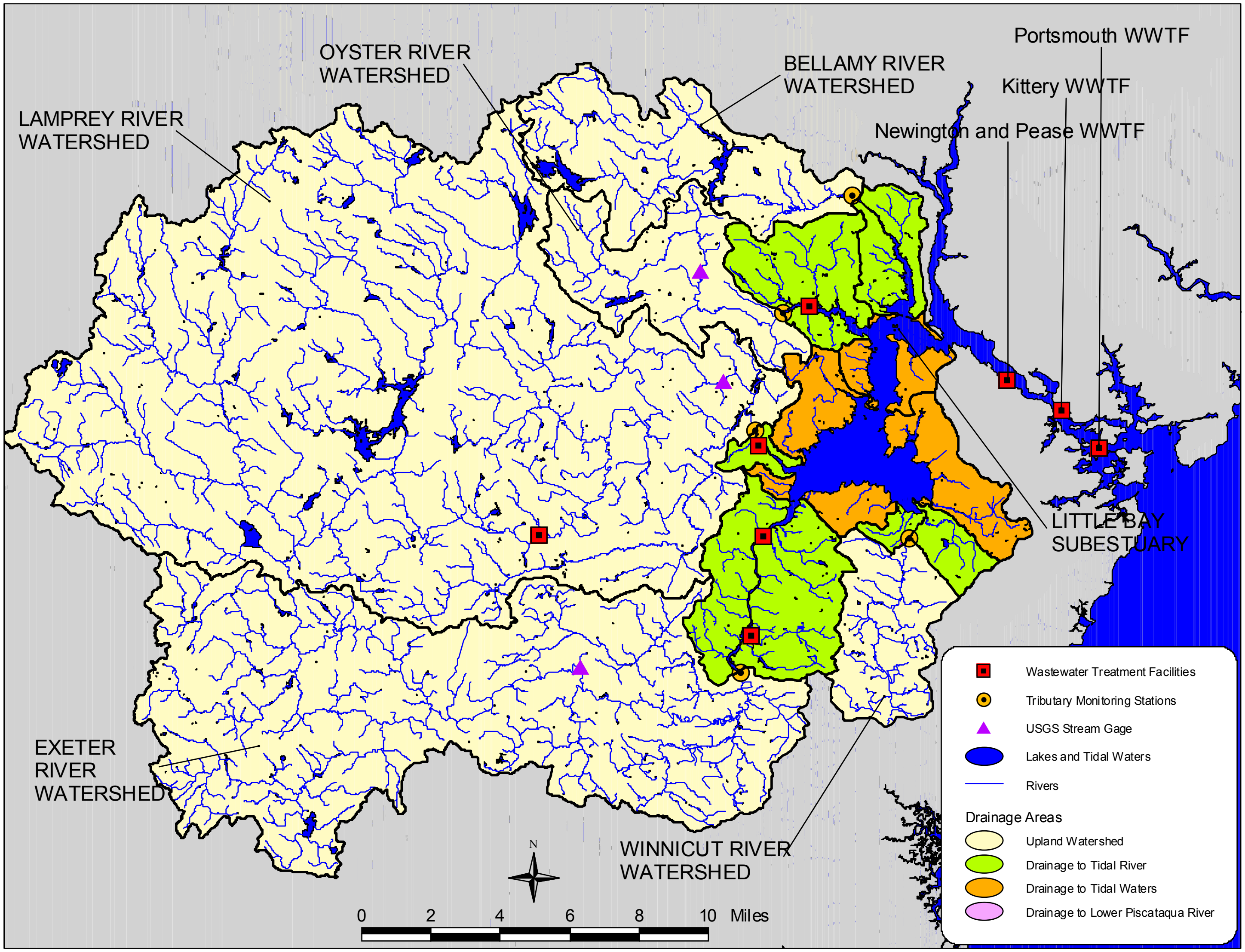

**Figure 11: Watershed for the Upper Piscataqua River subestuary**

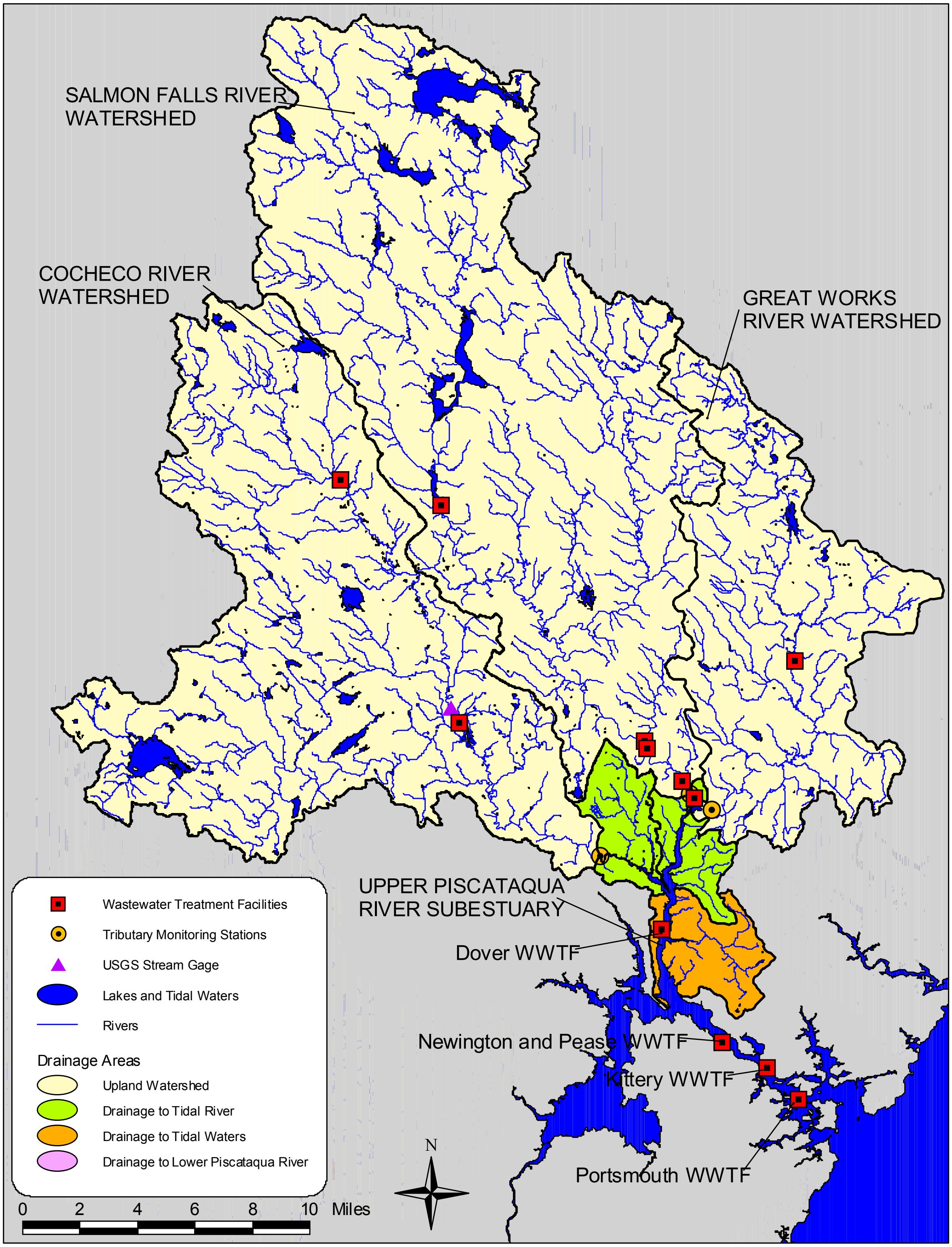

**Figure 12: Relationship between non-point source nitrogen yield from watersheds and land use for 2003-2004, 2005-2006, and 2007-2008**

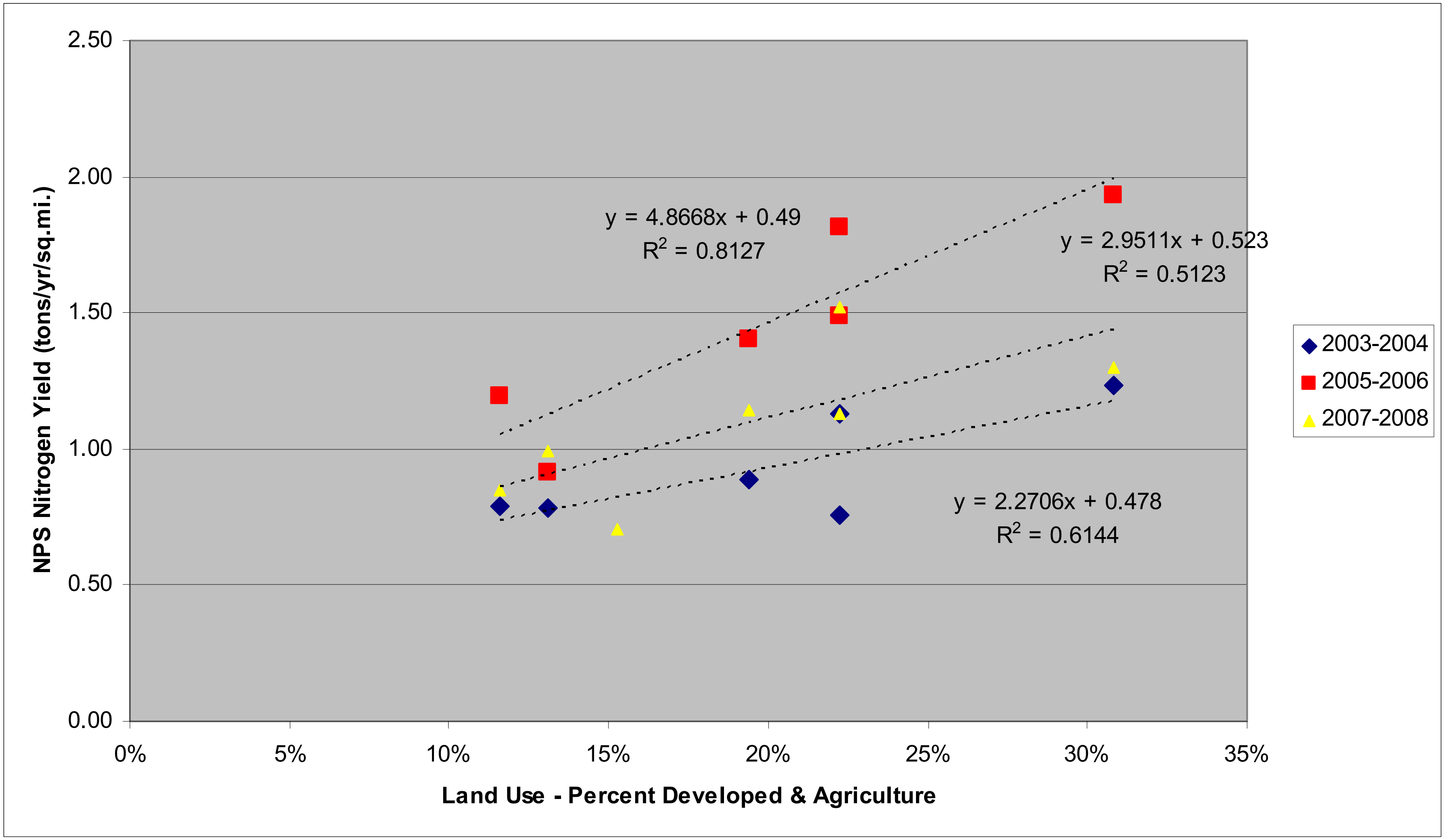

**Figure 13: Delivered nitrogen load from WWTFs to study subestuaries in 2003-2004, 2005-2006, and 2007-2008**

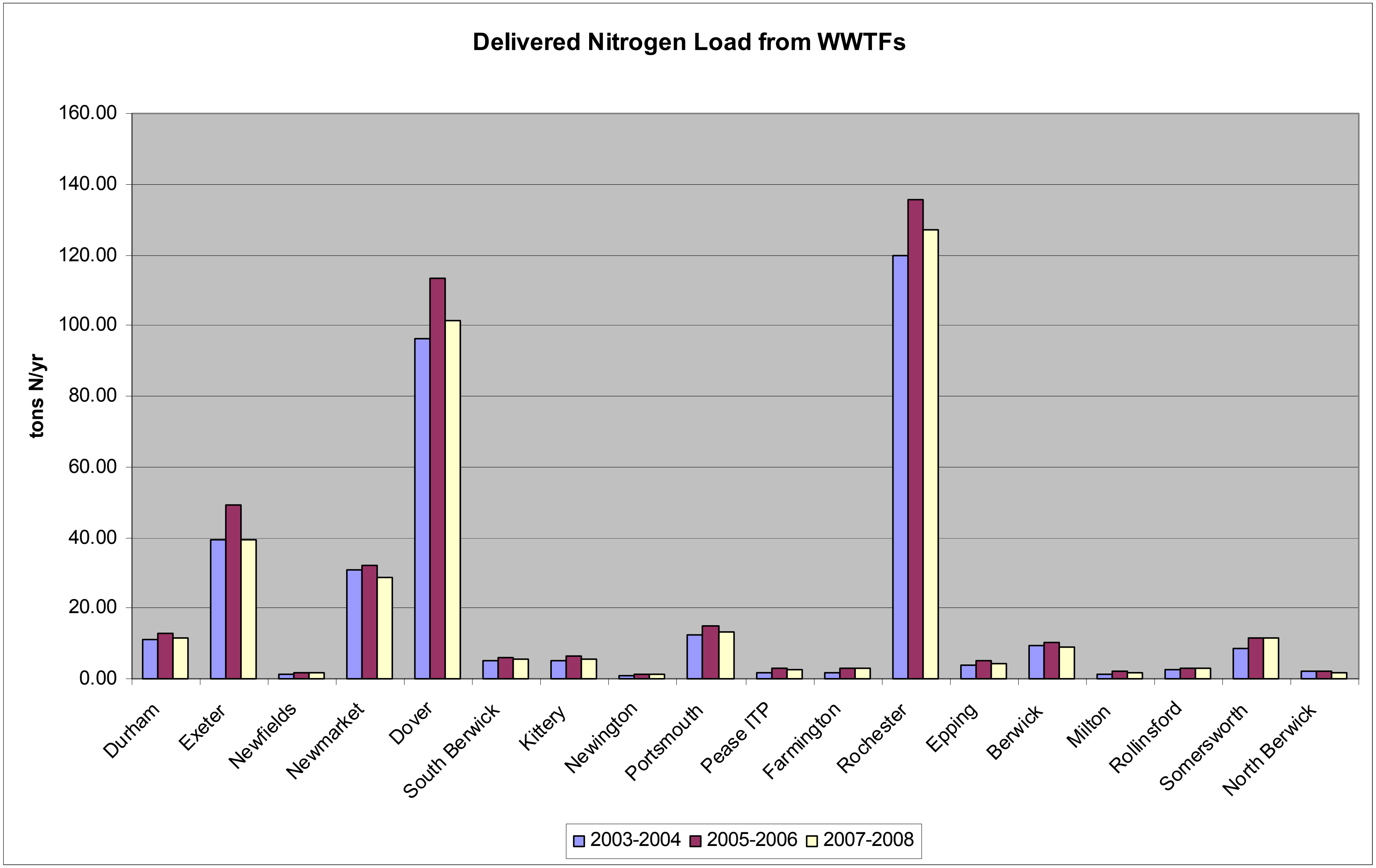

**Figure 14: Nitrogen loads from non-point sources in watersheds upstream of tidal dams in 2003-2004, 2005-2006, and 2007-2008**

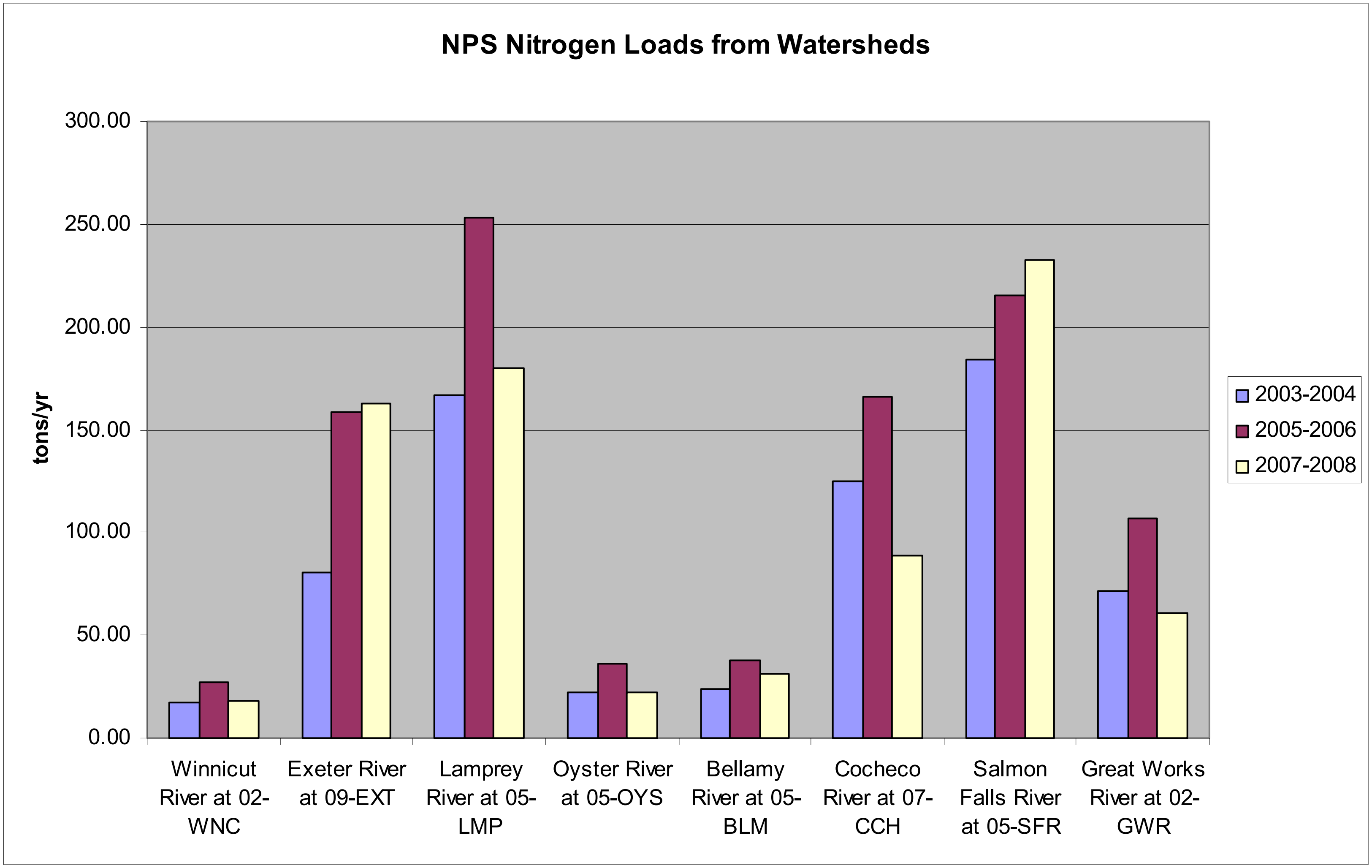

**Figure 15: Nitrogen loads from non-point sources in shorelands adjacent to study subestuaries in 2003-2004, 2005-2006, and 2007-2008**

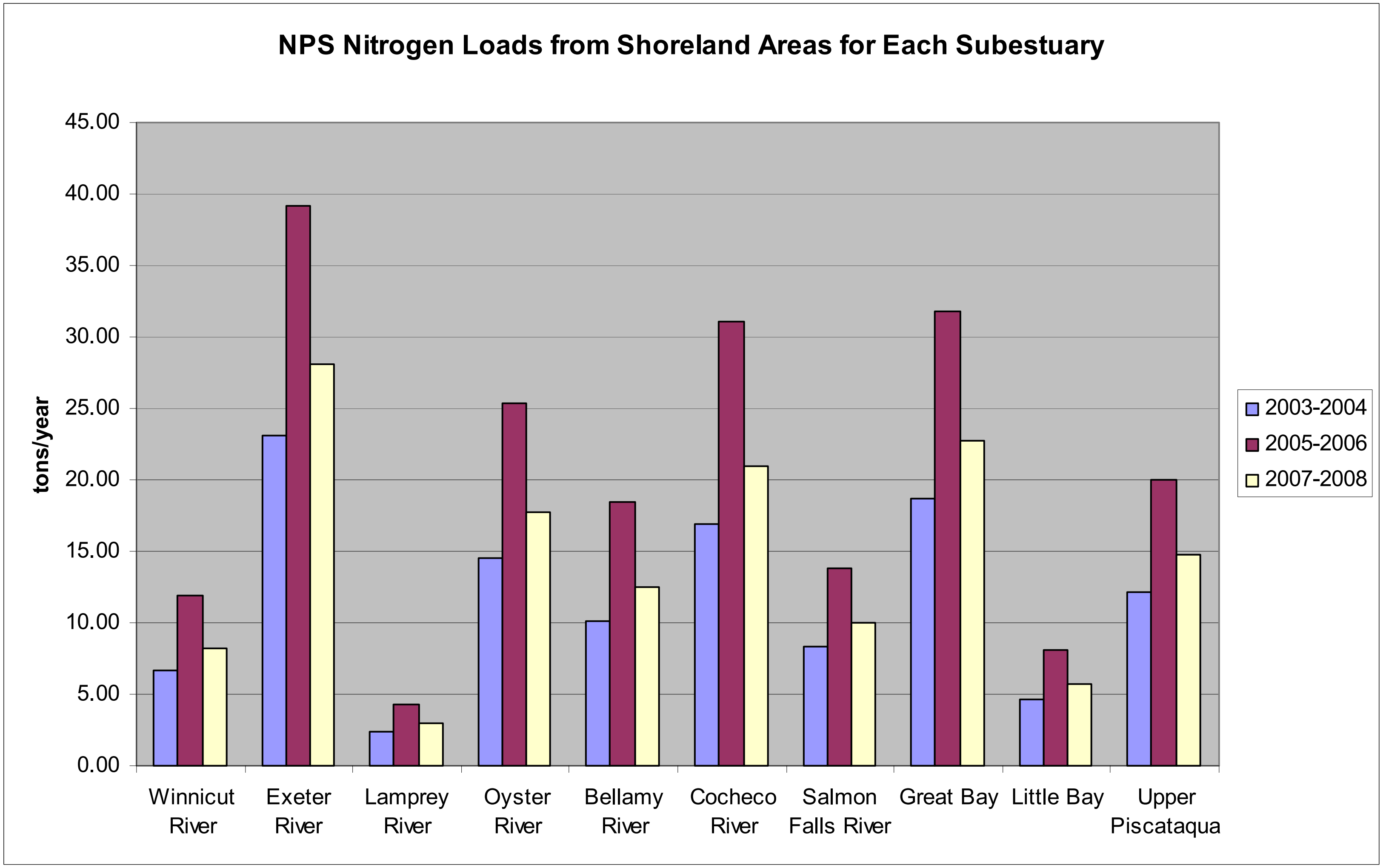

**Figure 16: Total nitrogen load to study subestuaries in 2003-2004, 2005-2006, and 2007-2008**